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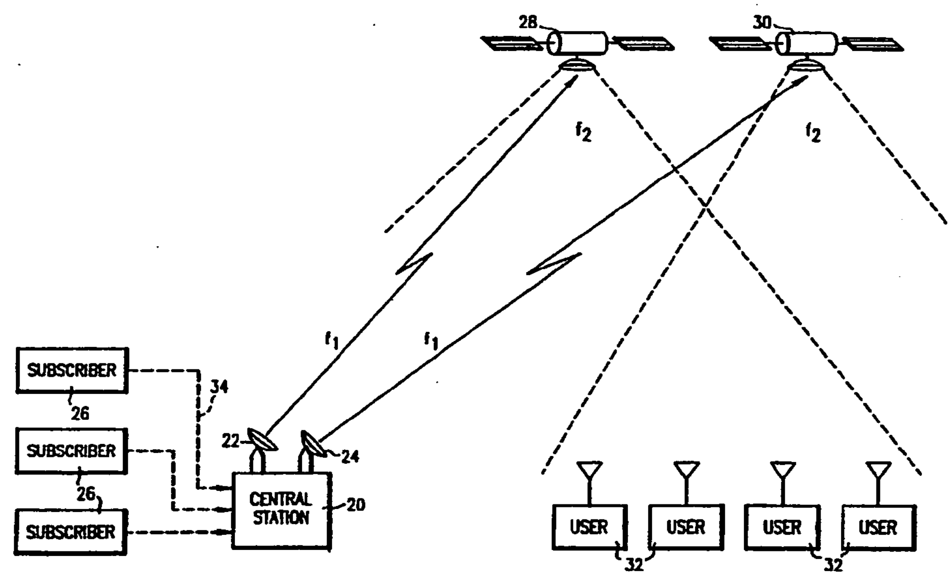

(57) Abstract

A mobile satellite communication system utilizes spread spectrum techniques to allow messages to be transmitted from a ground-based cenral station (20) to a number of essentially identical receiver terminals (32) through two or more relay satellites (28, 30) operating on the same downlink carrier frequency (f2) and covering the same geographic area. This arrangement allows the capacity of the system to be increased without the use of additional radio frequency spectrum on the downlink, and without reliance on directional tracking antennas at the receiving terminals. The system can also determine the positions of the receiver terminal (32) for navigational and tracking purposes.

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TITLE OF THE INVENTION:

COMMUNICATION SYSTEM EMPLOYING MULTIPLE RELAY SATELLITES OPERATING ON COMMON DOWNLINK FREQUENCY

BACKGROUND OF THE INVENTION:

The invention described and claimed herein relates generally to the field of communications, and is particularly concerned with a radio communication system in which signals are exchanged between ground-based transmitters and receivers through one or more relay satellites.

Many radio communication systems utilize satellites, particularly geostationary satellites, as signal relays. In fixed satellite communication systems, earth stations at fixed geographic locations transmit radio signals to a satellite which receives, amplifies, and rebroadcasts the transmissions at a shifted frequency to other earth stations at fixed locations. In this manner, point-to-point communication links can be established. Mobile satellite communication systems operate in much the same manner, although in this case the signals are relayed between mobile terminals which are carried by automobiles, trucks, airplanes, ships, or other movable platforms.

Both fixed and mobile satellite communications share certain limitations. A principal limitation, apart from the considerable cost involved in placing a satellite into orbit, relates to the maximum power available to operate the satellite. The amount of information which can be transmitted in a given bandwidth depends, in part, on the power available for transmission. The amplifiers on board the satellite are limited in their power output, and the electrical generating capacity of the satellite batteries and solar panels is also limited. Satellite power is thus a limited resource, and this will impose a limit on the total amount of information that can be processed by the communication system as a whole.

Another limitation arises from the fact that governmental regulations and international agreements designate limited frequency bands for use in satellite communication systems. Therefore, efficient use must be made of these frequency bands and communication techniques which are wasteful of radio spectrum must be avoided.

A further limitation results from the desirability of utilizing satellites in geostationary orbit as signal relays. Geostationary orbit is an equatorial orbit having a period of one day. To an observer on earth, a satellite in such an orbit appears to remain stationary at a fixed point in the sky, and can therefore serve as a fixed communication relay. Governmental regulations require a minimum spacing between satellites in order to avoid intersatellite interference. This, in turn, sets a limit on the total number of geostationary satellites which can be placed in orbit. Different satellites provide coverage of different portions of the earth, and demand is highest for satellites covering desirable markets. The signal handling capacity of these satellites must therefore be used in the most efficient manner possible.

These limitations have led to certain practices which have become common in the satellite communications industry. The high cost and limited number of satellites, for example, has led to the use of methods for allowing multiple earth stations to utilize the same satellite. One method is called frequency division multiple access (FDMA). In this technique, the allotted frequency spectrum is divided into a number of distinct bands. Different stations transmit in different frequency bands, and filters at the receiving stations block transmissions in all but the desired band.

Another method is called time division multiple access (TDMA). In this method, many different stations transmit in bursts using the same frequency band, but they are synchronized with one another so that the transmissions do not overlap in time.

In both FDMA and TDMA systems, satellite transponder power can limit the total amount of information that can be relayed. If a communication system has utilized all of the available transponder power, additional information can only be sent by utilizing another transponder on board the satellite. However, an increase in capacity using multiple transponder channels requires use of additional bandwidth, because each transponder on a given satellite operates in a different frequency band. Additional bandwidth may not always be available, especially for satellites placed in highly desirable locations. Moreover, the use of additional frequency channels requires the terrestrial transmitting and receiving stations to operate on multiple frequencies, which increases the cost and complexity of the communication system.

As an alternative, the capacity of a system can be increased by utilizing a transponder on a second satellite. If the second transponder operates at a frequency different from that of the first, spectrum usage is the same as in the situation where both transponders are carried by the same satellite. On the other hand, if the transponders on the two satellites operate in the same frequency band, interference may occur.

Fixed satellite communication systems which utilize two or more transponders operating at the same frequency on different satellites can avoid interference by using highly directional antennas. Such antennas may utilize large reflectors, phased antenna arrays, or other techniques to achieve the necessary degree of directionality. In mobile communication systems, however, directional antennas are undesirable because of their size, weight and complexity. Further, directional antennas must be aimed, and must track the satellite as the platform moves and changes direction. Even if tracking is possible, the cost of the necessary tracking equipment may become prohibitive when it is necessary to equip large numbers of mobile terminals at a low unit cost.

Small antennas, while more practical for mobile terminals, have a lower gain than large antennas. All else being equal, a system having a smaller receiving antenna will have a lower capacity than a system having a large antenna. Small antennas are generally less directional than large antennas, meaning that their gain is less dependent on orientation. Such small antennas cannot separate the transmissions of one satellite from those of another solely on the basis of the satellite positions.

To summarize, a conventional bandwidth-limited, mobile communication system which has reached the power limit of its satellite transponders cannot increase capacity by using additional transponders on the same satellite, since that would require additional bandwidth and complex user equipment, or by using a transponder on a second satellite operating at the same frequency, which would require multiple directional tracking antennas. A need exists, therefore, for a method by which the capacity of a satellite communication system can be increased without incurring any of these disadvantages.

SUMMARY OF THE INVENTION:

In accordance with the present invention, spread spectrum techniques are utilized to allow signals to be transmitted from a ground-based transmitting station to a plurality of receiver terminals through two or more relay satellites operating on the same downlink carrier frequency and covering the same geographic area. In this way, the capacity of the system can be increased without the use of additional radio bandwidth, and without reliance on directional tracking antennas at the receiver terminals. The use of a common downlink frequency also has the advantage of allowing all of the receiver terminals to be of essentially identical construction, which reduces the cost and complexity of the communication system.

In one aspect, the present invention relates to a radio communication system comprising means for generating messages to be transmitted; means for assigning said messages to first and second message groups; means for encoding said first and second message groups with mutually distinguishable codes; means for transmitting said first and second message groups; first and second elevated relay stations for receiving said first and second message groups, respectively, and for retransmitting said message groups at a common downlink carrier frequency, said relay stations having transmitting antennas which provide overlapping coverage of a common geographic area; and a plurality of receiver terminals located in said common geographic area for receiving said first and second message groups at said common downlink frequency, each of said receiver terminals including decoding means for decoding at least one of said first and second codes in order to allow messages to be received from at least one of said relay stations without interference from the other relay station.

Additional aspects of the invention relate to a method for transmitting messages from a central station to a plurality of receiver terminals using first and second relay stations operating at the same downlink frequency, and a method for expanding the capacity of a satellite communication system by employing additional relay satellites operating at the same downlink frequency. The invention has particular utility in satellite-based position determination and message transfer systems, but is also useful in other applications.

BRIEF DESCRIPTION OF THE DRAWINGS:

The various objects, advantages, and novel features of the present invention will be more readily apprehended from the following detailed description when read in conjunction with the appended drawings, in which:

Fig. 1 is a schematic illustration of a mobile satellite communication system incorporating the features of the present invention;

Fig. 2 is a schematic block diagram of the ground-based central station used in the communication system of Fig. 1;

Fig. 3 is a schematic diagram illustrating the general organization of software in the central station computer;

Fig. 4 is a flow chart which describes the operation of the message routing software used in the central station computer;

Fig. 5 is a block diagram of a modulator which forms a part of the transmitting equipment used at the central station;

Fig. 6 is a schematic diagram illustrating the format of the modulator output signals in Fig. 5;

Fig. 7 is a schematic diagram illustrating the principal transponder components used in the satellites of Fig. 1;

Fig. 8 is a schematic diagram illustrating the principal receiver components used in the receiver terminals of Fig. 1;

Fig. 9 is a schematic diagram of one of the decoder channels in Fig. 8; and

Fig. 10 is a schematic diagram of the message recovery circuit used in the receiver terminal of Fig. 8.

Throughout the drawings, like reference numerals will be understood to refer to like parts or components.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT:

Fig. 1 illustrates a satellite communication system operating in accordance with the principles of the present invention. The system comprises a fixed central station 20, a number of subscriber stations 26, two geostationary relay satellites 28 and 30 at spaced orbital positions, and number of mobile receivers 32 which are referred to as user terminals. The central station 20 operates two parabolic transmitting antennas 22 and 24. The system of Fig. 1 provides two types of communications, namely, message transmission (also referred to as paging) and radio position determination. For paging, the subscriber stations 26 generate text messages for specific ones of the user terminals 32. These messages are sent to the central station 20 over terrestrial communication links 34 which may, for example, comprise telephone lines, microwave links or optical fiber links. The central station 20 collects the messages and transmits them to the user terminals 32 by means of the two relay satellites 28 and 30. The user terminals 32 may, if desired, have the capability to reply to the central station 20 with their own text messages.

For position determination, the central station 20 transmits an interrogation signal (which may also carry message data) that is relayed to the user terminals 32 through one or both of the satellites 28, 30, and the user terminals 32 respond by transmitting reply signals back to the central station through both satellites. The central station 20 then performs time difference of arrival calculations to determine the positions of individual user terminals 32. The position data may then be made available to the subscribers 26 and, optionally, to the involved user terminals 32.

Further details of the message exchange and position determination functions may be found in U.S. Patent 4,359,733, issued to G.K. O'Neill on November 16, 1982; in U.S. Patent 4,744,083, issued to G.K. O'Neill and L.O. Snively on May 10, 1988; in copending U.S. patent application Serial No. 641,385, filed by G.K. O'Neill and L.O. Snively on August 16, 1984; and in copending U.S. patent application Serial No. 260,614, filed by M. Motamedi on October 21, 1988; all of said patents and applications being expressly incorporated herein by reference.

One application of a system of the type shown in Fig. 1 is to provide tracking and paging services for a number of vehicle fleets operated by different companies (the latter corresponding to the subscribers 26). Each subscriber 26 operates a number of vehicles (e.g., trucks, automobiles, ships, railroad cars, or the like) and each vehicle carries a mobile user terminal 32. The central station 20 determines the locations of each user terminal 32, and informs each subscriber 26 of the locations of its associated user terminals. In addition, the central station 20 accepts messages from each subscriber 26, sorts the messages, and transmits them to the appropriate user terminals 32. Message and position information for each subscriber 26 is confidential with respect to the other subscribers. In the description which follows, primary emphasis will be placed on the paging aspects of the system, although it should be understood that position determination and paging functions may be carried out simultaneously using the apparatus and methods disclosed in the patents and applications mentioned previously.

The partitioning of the outgoing message traffic between the two satellites 28, 30 of Fig. 1 allows the message handling capacity of the system to be increased beyond that which would be obtained in a single satellite system. As will be described, this result can be achieved without increasing the amount of radio spectrum utilized, by operating both satellites on the same uplink and downlink carrier frequencies and by taking steps to eliminate interference between the signals transmitted to and received from the two satellites. On the uplink side, interference is eliminated by utilizing highly directional transmitting antennas which are aligned toward the respective satellites. On the downlink side, interference is eliminated by encoding the message transmissions relayed through the two satellites using mutually distinguishable codes, and by providing the user terminals with equipment for decoding one or both codes.

Referring again to Fig. 1, the first directional antenna 22 at the central station 20 transmits messages to the first satellite 28 at an uplink frequency f_1. The second directional antenna 24 transmits messages to the second satellite 30 at the same uplink frequency f_1. Energy from the first transmitting antenna 22 is focused on the first satellite 28, but not on the second satellite 30. Conversely, energy from the second transmitting antenna 24 is focused on the second satellite 30, but not on the first satellite 28. The satellites 28, 30 shift the uplink transmissions to the same downlink frequency f_2, and both satellites 28, 30 provide coverage to the same geographic region which encompasses the user terminals 32. In practice, the satellites may use multiple antennas or overlapping spot beams to provide the desired geographic coverage.

The user terminals 32 can potentially receive transmissions from both satellites since the transmissions will have the same frequency and approximately the same power level. In order to avoid the interference which would otherwise result in this situation, the signal transmissions are encoded by the central station 20 and are decoded by the user terminals 32 using spread spectrum techniques, as will be discussed in more detail below. The use of spread spectrum transmissions allows the signal traffic to be divided between the two satellites 28, 30 without requiring an additional downlink frequency, and without resorting to the use of directional antennas at the user terminals.

Since radio spectrum allocations are somewhat easier to obtain for narrow beam transmissions than for broad beam transmissions, the use of a single uplink frequency f_1 is desirable but not essential. The objective of minimizing the spectrum requirement is substantially met by the use of a single downlink frequency f_2 for the transmissions taking place between the satellites 28, 30 and the user terminals 32, since these transmissions cover a much wider geographic area than the uplink transmissions.

Fig. 2 is a functional block diagram of the central station 20. The subscribers 26 (not shown) generate messages on input lines 36. These messages may, for example, consist of ASCII characters in the form of digital electronic signals. Along with the message data, the subscribers specify the destination of each message by identifying a specific user terminal 32. A communications interface 38 receives the subscriber information and routes it to a computer 40. The computer 40 receives the information, temporarily stores the messages, identifies their destinations, and routes each message to one of two equipment chains 42, 44.

The two equipment chains 42, 44 contain similar equipment. Referring first to the chain 42, a modulator 46 spreads the data stream onto a pseudo-noise (PN) code according to the direct sequence spread spectrum modulation technique. The modulator 46 also modulates the spread signal onto an intermediate frequency (IF) carrier using biphase shift keying. An up converter 48 shifts the frequency of the IF carrier to a microwave frequency f_1 on the order of several gigahertz. A high power amplifier 50 increases the power of the microwave signal for transmission. The directional transmitting antenna 22 focuses the radiated energy of the amplified signal from the first equipment chain 42 to the satellite 28 of Fig. 1. The second equipment chain 44 performs identical functions using a modulator 52, up converter 54 and high power amplifier 56, but this chain processes messages which are intended for transmission by the second directional antenna 24 to the second satellite 30 of Fig. 1.

The up converters 48, 54 of the two equipment chains 42, 44 shift their respective IF carriers to the same uplink frequency f_1. However, since each of the two parabolic transmitting antennas 22, 24 focuses its power on only one satellite, interference at the satellites does not occur even though a common uplink frequency is employed. At the user level, interference is avoided by virtue of the fact that the modulators 46, 52 of the two equipment chains 42, 44 utilize different PN codes, allowing the user terminals 32 to receive the signal from only one satellite without requiring a directional antenna.

The computer 40 performs message routing and message stream aggregation using known packet switching techniques. The computer hardware may, for example, consist of an HP 850 system manufactured by Hewlett Packard Corporation. The interface to the subscriber equipment will vary according to the specific requirements of each subscriber, but may include a modem or coder/decoder unit connected by telephone lines to similar equipment at the subscriber site.

Figure 3 illustrates the general organization of software in the computer 40. An operating system 58 provides the highest level of control of the computer and establishes the system environment for various application programs. An outbound message signal processing program 60 is one such application. Other application programs 62 (e.g., for billing and accounting functions) also exist and may be called to run on the same computer. Within the outbound message processing program 60, the software is divided into several functional modules. The outbound message processing control module 64 regulates the sequence in which other modules are called. A routing module 66 routes messages to one of the two equipment chains 42, 44 (Fig. 2). The remaining modules 68 control the formatting and sequencing of the messages, the generation of timing data for use in position calculations, and other functions. For the purposes of the present invention, only the routing module 66 is of importance and the other software modules need not be described further.

Fig. 4 is a flow chart which describes the operation of the routing module 66. The module begins at an entry point 70 when called from the outbound message processing control module 64 (Fig. 3). In block 72, the computer executes an input operation which reads an identification code for the message destination from the information received from the subscriber. The computer then performs a table look-up in block 74 to determine which PN code has been assigned to the user terminal that is to receive the message. The table 76 lists all user terminals according to identification code. For each identification code, the table 76 indicates whether the receiver is capable of decoding a first PN code, a second PN code, or both PN codes.

After executing the table look-up, the computer proceeds to a decision block 78. If the receiver is capable of decoding only the first PN code, the computer executes a first output operation in block 80 which passes the message to the first equipment chain 42 of Fig. 2. If the receiver is capable of decoding only the second PN code, the computer executes a second output operation in block 82 which passes the message to the second equipment chain 44 of Fig. 2. If the receiver is capable of decoding both PN codes, the computer executes a decision operation in block 84 which selects one of the two output operations 80, 82.

The select operation in block 84 may select an equipment chain in such a manner as to equalize signal traffic between the two satellites 28, 30 (Fig. 1), to shunt signal traffic away from a satellite which has reached its message handling capacity, or to avoid failed equipment in one of the equipment chains or in one of the satellites. In certain cases, the message may be passed to both equipment chains so that it will be transmitted to the intended user terminal 32 through both satellites simultaneously. This may be desirable as a means for insuring that certain critical messages reach the user, or as a means for carrying out position determination using techniques to be discussed shortly.

After executing the appropriate output operation in block 80 or 82, the computer reaches an exit point 86 and execution of the routing module terminates. The computer may then execute another functional module or re-enter the routing module, as directed by the outbound message processing control module 64 of Fig. 3.

Fig. 5 is a block diagram of the modulator 46 in the first equipment chain 42 of Fig. 2. The modulator 52 in the second equipment chain 44 is essentially identical except for the particular PN code employed, and the description which follows applies to both.

The modulator 46 performs two functions, namely, spreading the output data stream from the computer 40 onto a pseudo-noise (PN) code, and modulating the spread data stream onto an intermediate frequency (IF) carrier. A clock 88 generates a periodic signal and a first divider chain 90 generates a 1200 Hz signal from the clock signal. A mixer 92 shifts the input data signal on line 94 to 1200 Hz. A second divider chain 96 generates a 1.112 MHz signal from the clock signal which drives a pseudo-noise (PN) generator 98 at a 1.112 megachip per second (Mcps) chip rate. The PN generator 98, in turn, generates a 1.112 Mcps pseudo-noise code which consists of a Gold code having a length of $(2^{17}-1)$ chips. A second mixer 100 spreads the 1200 Hz data signal over the 1.112 Mcps PN code. A biphase shift keyed (BPSK) modulator 102 modulates a 70 MHz carrier with the spread data. A bandpass filter 104 eliminates spurious signals outside a pass band centered at 70 MHz, and produces an output signal on line 106 which is applied as an input to the up converter 48 of Fig. 2.

Fig. 6 is a schematic diagram illustrating the time domain organization of the modulator output signal in Fig. 5. The output signal 108 is divided into successive frames 110, each frame comprising one repetition of the $(2^{17}-1)$ chip PN sequence. Each frame 110 is further subdivided into a number of parts. An initial sequence (L1) denotes the beginning of the frame and may be an all-ones portion of the PN sequence. A succession of messages 112 addressed to individual user terminals follows the L1 sequence. A parity check (PC) follows the last message, and an ending sequence (L2) marks the end of the frame. Each message 112 contains two portions, the first portion 114 comprising an identification code which designates the intended user terminal. This is the same information that is used in the look-up table 76 of the routing module 66 to select an equipment chain 42, 44 for the message. The remaining portion 116 of the message consists of the ASCII text or other data that is being sent by the subscriber to the user terminal.

Fig. 7 is a schematic diagram illustrating the principal transponder components of the first satellite 28 in Fig. 1, it being understood that the second satellite 30 is substantially identical. The satellite includes an antenna 118 which collects energy from the uplink signals at frequency f_1 and also focuses the downlink transmissions at frequency f_2. The uplink signals pass through a diplexer 120 to a bandpass filter 122 which only passes signals in a narrow frequency band that includes the uplink frequency f_1. A frequency converter 124 shifts the frequency f_1 of the uplink signal to the downlink frequency f_2. A transmitter 126 increases the total power of the downlink signal, which then passes through the diplexer 120 to the antenna 118 and propagates back to earth.

The user terminals 32 (Fig. 1) receive the message signals after they are retransmitted by the relay satellites 28, 30. The retransmitted signals are sequences of individual messages intended for specific ones of the user terminals 32. The receiver portion of each user terminal 32 includes message processing means to identify and display those messages from the received signal that are specifically directed to that particular user terminal. Optionally, the user terminals 32 may also transmit reply signals to the central station 20 via the satellites 28, 30 in order to send return messages to the subscriber stations 26 or to allow the user positions to be calculated by the central station 20, as described in the patents and copending patent applications cited above. Alternatively, user terminals which are equipped to decode both of the PN codes associated with the respective satellites 28, 30 can calculate their own positions based on the relative arrival times of the signals received from the two satellites, assuming that the satellite positions are known and the signals are encoded with their transmission times. The calculated position data can be returned to the central station 20 using only one of the two satellites 28, 30, and the data may then be sent to the relevant subscriber stations 26. As a further alternative, the user terminals can themselves measure the arrival times of the signals received from the two satellites, and the arrival time data can be returned to the central station through one of the satellites. The user positions can then be calculated at the central station and made available to the subscriber stations 26 (and, optionally, to the user terminals 32 as part of the next paging cycle).

Figure 8 shows the general organization of subsystems in the receiver portion of a user terminal 32. The user terminal 32 utilizes a small, fixed omnidirectional antenna 128 to receive transmissions from the satellites 28 and 30 of Fig. 1. A low noise amplifier 130 increases the power of the received signal. A down converter 132 referenced to a local oscillator 134 converts the received signal from a microwave frequency on the order of several gigahertz to a lower frequency of about 70 MHz suitable for intermediate frequency processing. A bandpass filter 136 blocks all energy in the received signal except frequencies centered around 70 MHz. A biphase shift keyed (BPSK) demodulator 138 removes the 70 MHz biphase modulated carrier of the received IF signal to yield a 1.112 Mcps spread signal. The BPSK demodulator 138 also produces a signal for controlling the frequency of the local oscillator 134.

In the embodiment shown, the user terminal 123 includes separate decoding channels 140 and 142 for removing first and second PN codes, respectively, from the spread signals. A divider 144 splits each spread signal into two identical signals, and directs the signals to the decoding channels 140, 142. The outputs of the decoding channels 140, 142 are applied as inputs to a message recovery circuit 146, which in turn drives a display 148 or produces a command signal. In instances where it is desired to confine a particular user terminal to a single PN code, only one decoding channel is used and the divider 144 is omitted.

Fig. 9 shows the decoding channel 140 in detail, the other decoding channel 142 being substantially identical. A mixer 150 combines the data stream from the divider 144 with a locally generated PN code produced by a code generator 151 in order to despread the received signal. The mixer output is applied as an input to a demodulator 152 which recovers the data when the PN generator 151 is operating in synchronism with the incoming signal. The frequency of the PN generator

151 is adjusted by a voltage controlled oscillator 153, which is in turn controlled by a feedback signal from the demodulator 152. Various methods for acquisition and synchronization of PN-coded signals, such as serial searching and delay locked loops, are known in the field of spread spectrum communications. Any of these techniques may be used in the practice of the present invention.

The output of the decoding channels 140, 142 of Fig. 8 are despread baseband signals comprising a plurality of messages. The message recovery circuit 146 isolates those messages which are directed to the specific user terminal 32 of interest. This circuit, shown in more detail in Fig. 10, includes a buffer 154 for storing the outputs of the decoding channels 140, 142. Despread signals stored in the buffer 154 are serially read into a correlator 156. The correlator 156 comprises registers having sufficient size to store the destination and message information for a single message 112 (Fig. 6). Another set of registers in the correlator stores the identification code assigned to the user terminal. The received identification information is continuously compared with the stored identification code for the user terminal, and when correlation is achieved, the associated message data is transferred to one of two different outputs depending on the type of data being sent. If the data comprises a message that is intended for a human operator, it is transferred to a display memory 158. The display memory 158 directs the message data to the display unit 148 of Fig. 8 so that the message can be read by the user. The display unit 148 may comprise a visual display such as a light emitting diode (LED) array, liquid crystal display (LCD) or cathode ray tube (CRT), an audible readout such as a voice synthesizer, or a hard copy output device such as a printer. On the other hand, if the data comprises control data that is intended to control a physical device connected to the user terminal, a command signal is produced and is applied as input to the controlled device. As an example, a command signal of this type may be used to control the refrigeration unit in a truck or railroad car that is equipped with a user terminal 32.

If a reply capability is desired, the user terminal may be provided with an input device such as a keyboard or voice digitizer, together with suitable transmitting circuitry for transmitting reply signals to the central station 20 through one or both of the satellites 28, 30. The transmitting circuitry may be enabled by reply trigger outputs from the decoding channels 140, 142 of Fig. 8. These outputs occur whenever the initial bits of an incoming signal having the appropriate PN code are detected, regardless of whether the associated message data is intend for that particular user terminal. This allows a given user terminal to send data (or a position request) to the central station 20 once during each paging cycle, even if no message data is being sent to the user terminal.

It should be emphasized that the use of a common carrier frequency for the downlink signals, in addition to reducing radio spectrum usage, has the advantage of allowing all of the user terminals 32 to be of substantially identical construction since only one set of oscillators, filters and other frequency-selective components is required. This allows substantial savings in cost, size and weight to be realized, and also allows commonality of spare parts, maintenance and test equipment, and so on. Although two PN decoders are required in the user terminals in order to allow message transmissions to be received from both satellites, these decoders can be implemented in digital circuitry of relatively small size and low cost. In situations where different PN codes are assigned to different groups of user terminals, the necessary PN decoders may be provided as replaceable plug-in components so that the user terminals can be manufactured as identical units. In any case, the resulting system is considerably less complex than, for example, one in which different groups of user terminals are required to operate on different frequencies or a given user terminal is required to receive signals on more than one frequency. Fault tolerance is also increased since the failure of the downlink frequency channel on one satellite will not disable the entire system.

Although the present invention has been described with reference to a preferred embodiment, the invention is not limited to the details thereof. For example, the communication system may be expanded to include additional satellite relays and PN codes, and the spread spectrum modulation signal may be carried out aboard the satellites rather than at the central station. Further, it should be noted that various types of signal relays other than satellites may be employed in the practice of the invention. Other substitutions and modifications will occur to those of ordinary skill in the art, and all such substitutions and modifications are intended to fall within the scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. A radio communication system comprising:

means for generating messages to be transmitted;

means for assigning said messages to first and second message groups;

means for encoding said first and second message groups with mutually distinguishable codes;

means for transmitting said first and second message groups;

first and second elevated relay stations for receiving said first and second message groups, respectively, and for retransmitting said message groups at a common downlink carrier frequency, said relay stations having transmitting antennas which provide overlapping coverage of a common geographic area; and

a plurality of receiver terminals located in said common geographic area for receiving said first and second message groups at said common downlink carrier frequency, each of said receiver terminals including decoding means for decoding at least one of said first and second codes in order to allow messages to be received from at least one of said relay stations without interference from the other relay station.

2. A radio communication system as claimed in claim 1, wherein said encoding means comprises means for spread spectrum modulating said first and second message groups using different pseudo-noise codes.

3. A radio communication system as claimed in claim 1, wherein the decoding means of at least one of said receiver terminals is effective to decode both of

said first and second message groups in order to allow messages to be received from both of said relay stations.

4. The radio communication system as claimed in claim 1, wherein the messages in said first and second message groups each contain an identification portion designating one of said receiver terminals and an information portion containing message data intended for said designated receiver terminal, and wherein each of said receiver terminals comprises means for comparing the identification portions of received messages with a stored identification code and for recovering the message data from messages having identification portions matching said stored identification code.

5. A radio communication system as claimed in claim 4, wherein each of said receiver terminals further comprises means for displaying said recovered message data.

6. A radio communication system as claimed in claim 1, wherein said assigning means comprises a stored look-up table indicating whether the decoding means of a given receiver terminal is capable of decoding said first code or said second code.

7. A radio communication system as claimed in claim 1, wherein said transmitting means includes first and second directional transmitting antennas aligned in the direction of said first and second elevated relay stations, respectively, for transmitting said first and second message groups to said relay stations at a common uplink carrier frequency.

8. A radio communication system as claimed in claim 1, wherein said assigning means, said encoding means and said transmitting means are located at a transmitting station having a fixed location.

9. A radio communication system as claimed in claim 8, wherein said means for generating messages comprises a plurality of subscriber stations connected to said transmitting station.

10. A radio communication system as claimed in claim 1, wherein said first and second elevated relay stations comprise geostationary satellites.

11. A radio communication system as claimed in claim 1, wherein at least one of said receiver terminals comprises a mobile terminal.

12. A radio communication system as claimed in claim 1, wherein each of said receiver terminals includes a nondirectional receiving antenna.

13. A method for transmitting messages from a central station to a plurality of receiver terminals using first and second elevated relay stations operating at the same downlink carrier frequency, comprising the steps of:

assigning said messages to first and second message groups;

encoding said first and second message groups with mutually distinguishable codes;

transmitting said first and second message groups from said central station to said first and second elevated relay stations, respectively;

retransmitting said first and second message groups at a common downlink carrier frequency from said respective first and second elevated relay stations to a common geographic area containing said receiver stations;

decoding at least one of said first and second codes at each of said receiver terminals in order to allow messages to be received by said receiver terminal from at least one of said relay stations without interference from the other relay station.

14. A method as claimed in claim 13, wherein said encoding step comprises spread spectrum modulating said first and second message groups using different pseudo-noise codes.

15. A method as claimed in claim 13, wherein the messages in said message groups each contain an identification portion designating one of said receiver terminals and an information portion containing message data intended for said designated receiver terminal, and further comprising the steps of:

comparing the identification portions of received messages with an identification code stored in the receiver terminal;

recovering the message data from messages having identification portions matching said stored identification code.

16. A method as claimed in claim 15, further comprising the step of displaying said message data at the receiver terminal.

17. A method as claimed in claim 13, further comprising the steps of:

generating messages intended for specific ones of said receiver terminals at a plurality of subscriber terminals;

transmitting said messages from the subscriber stations to the central station.

18. A method as claimed in claim 13, wherein the step of assigning said messages to first and second message groups comprises carrying out a look-up operation to determine from stored data whether the decoding means of a given receiver terminal is capable of decoding said first code or said second code.

19. A method as claimed in claim 13, wherein the step of transmitting said first and second message groups to said first and second elevated relay stations is carried out at a common uplink carrier frequency using directional transmitting antennas.

20. A method for expanding the capacity of a radio communication system in which messages are transmitted from a central station to a plurality of receiver terminals by means of a relay satellite, comprising the steps of partitioning the messages into at least two message groups, encoding said message groups with mutually distinguishable codes, transmitting one message group to said receiver terminals through the first relay satellite, transmitting the other message group to the same receiver terminals in the same geographic area using an additional relay satellite operating at the same downlink carrier frequency, and decoding at least one of the codes at each receiver terminal in order to allow messages to be received at said terminal from at least one relay satellite

without interference from the other relay satellite.

AMENDED CLAIMS

[received by the International Bureau on 7 September 1990 (07.09.90); original claims 13 and 15 amended; other claims unchanged (1 page)]

said respective first and second elevated relay stations to a common geographic area containing said receiver terminals; and

decoding at least one of said first and second codes at each of said receiver terminals in order to allow messages to be received by said receiver terminal from at least one of said relay stations without interference from the other relay station.

14. A method as claimed in claim 13, wherein said encoding step comprises spread spectrum modulating said first and second message groups using different pseudo-noise codes.

15. A method as claimed in claim 13, wherein the messages in said message groups each contain an identification portion designating one of said receiver terminals and an information portion containing message data intended for said designated receiver terminal, and further comprising the steps of:

comparing the identification portions of received messages with an identification code stored in the receiver terminal; and

recovering the message data from messages having identification portions matching said stored identification code.

16. A method as claimed in claim 15, further comprising the step of displaying said message data at the receiver terminal.

17. A method as claimed in claim 13, further comprising the steps of:

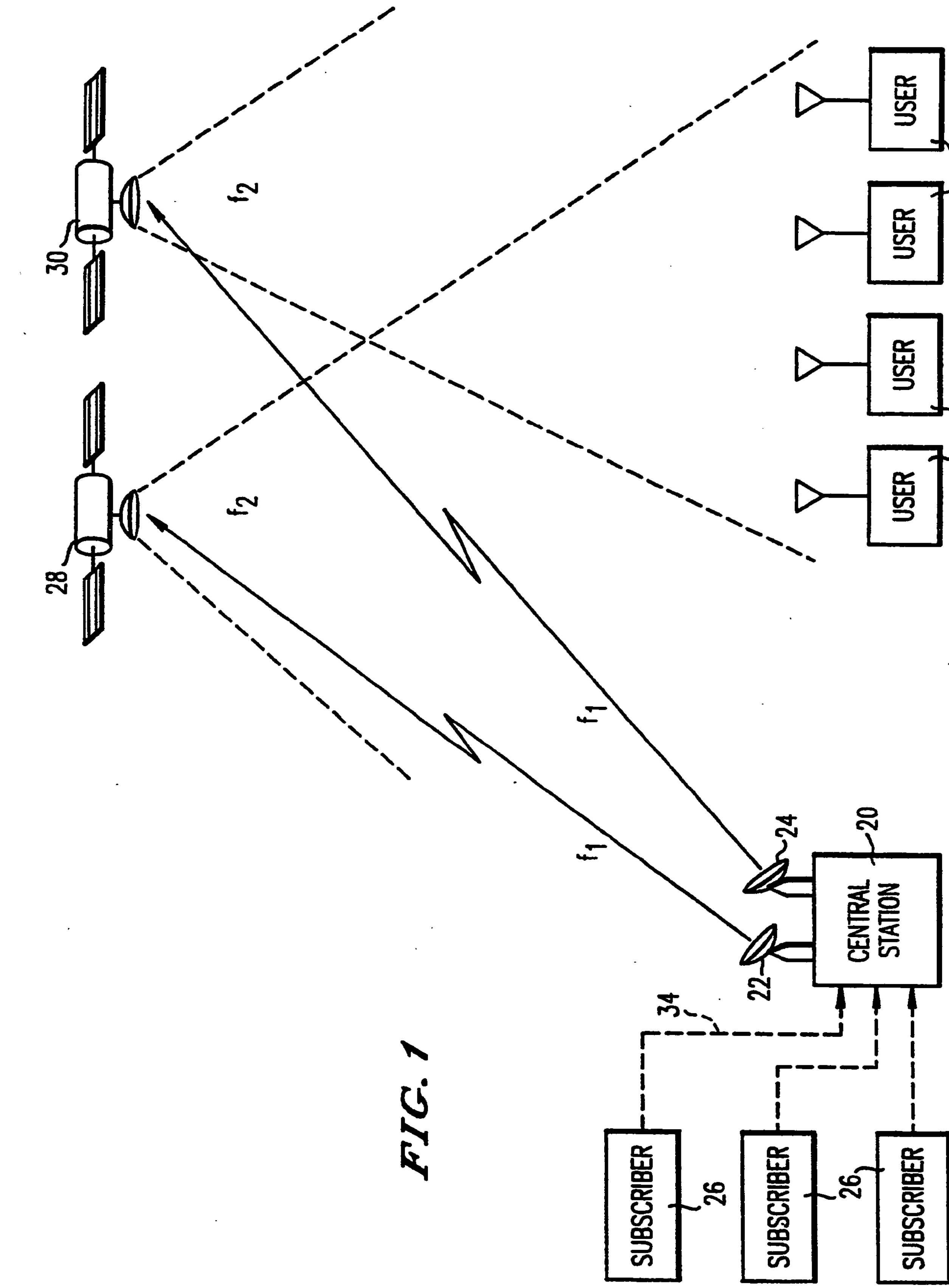
30
28
f_2
f_2
f_1
f_1
USER
USER
USER
USER
32
32
24
20
22
CENTRAL STATION
34
SUBSCRIBER
SUBSCRIBER
SUBSCRIBER
26
26
26

FIG. 1

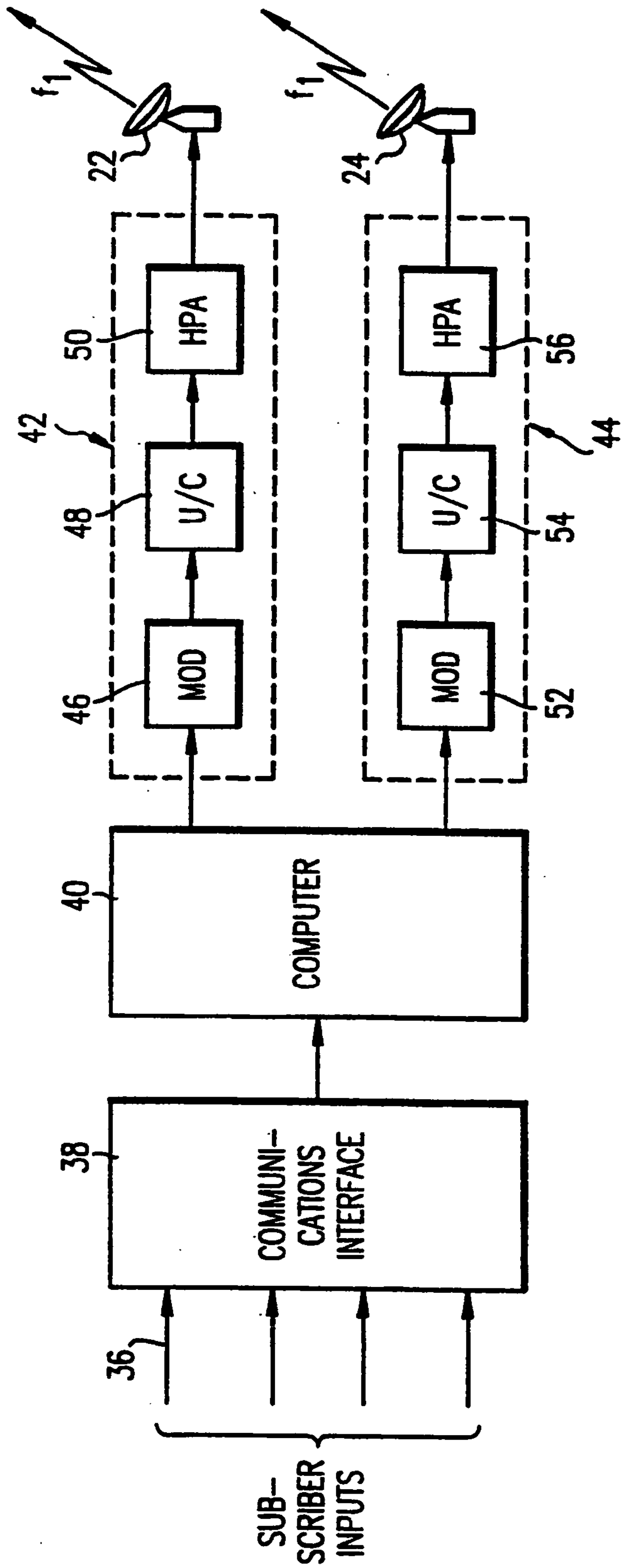
f1
f1
22
24
HPA
50
HPA
56
42
44
U/C
48
U/C
54
MOD
46
MOD
52
40
COMPUTER
38
COMMUNI-
CATIONS
INTERFACE
36
SUB-
SCRIBER
INPUTS

FIG. 2

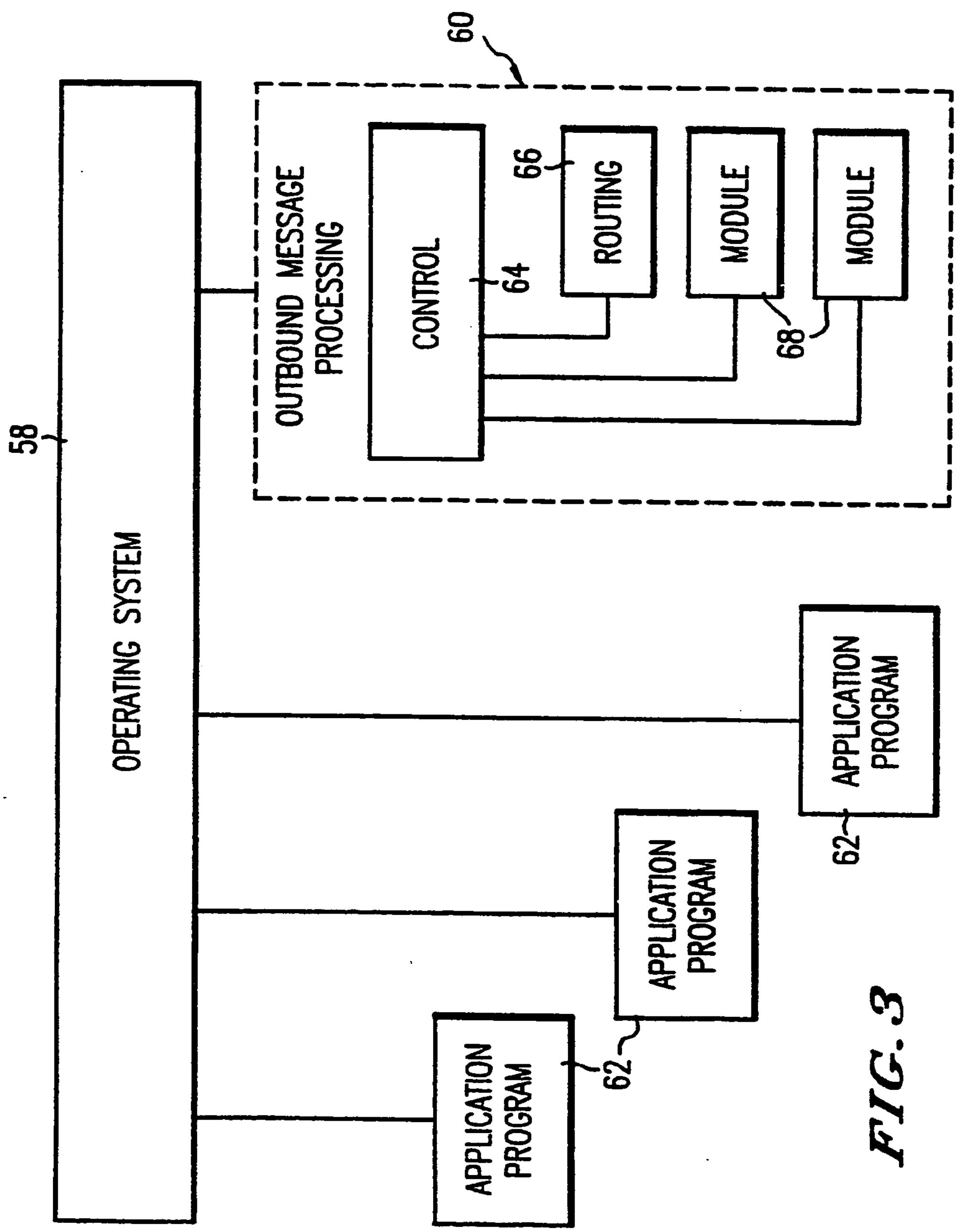
58
OPERATING SYSTEM
60
OUTBOUND MESSAGE PROCESSING
CONTROL
64
66
ROUTING
MODULE
MODULE
68
APPLICATION PROGRAM
APPLICATION PROGRAM
APPLICATION PROGRAM
62
62
62

FIG. 3

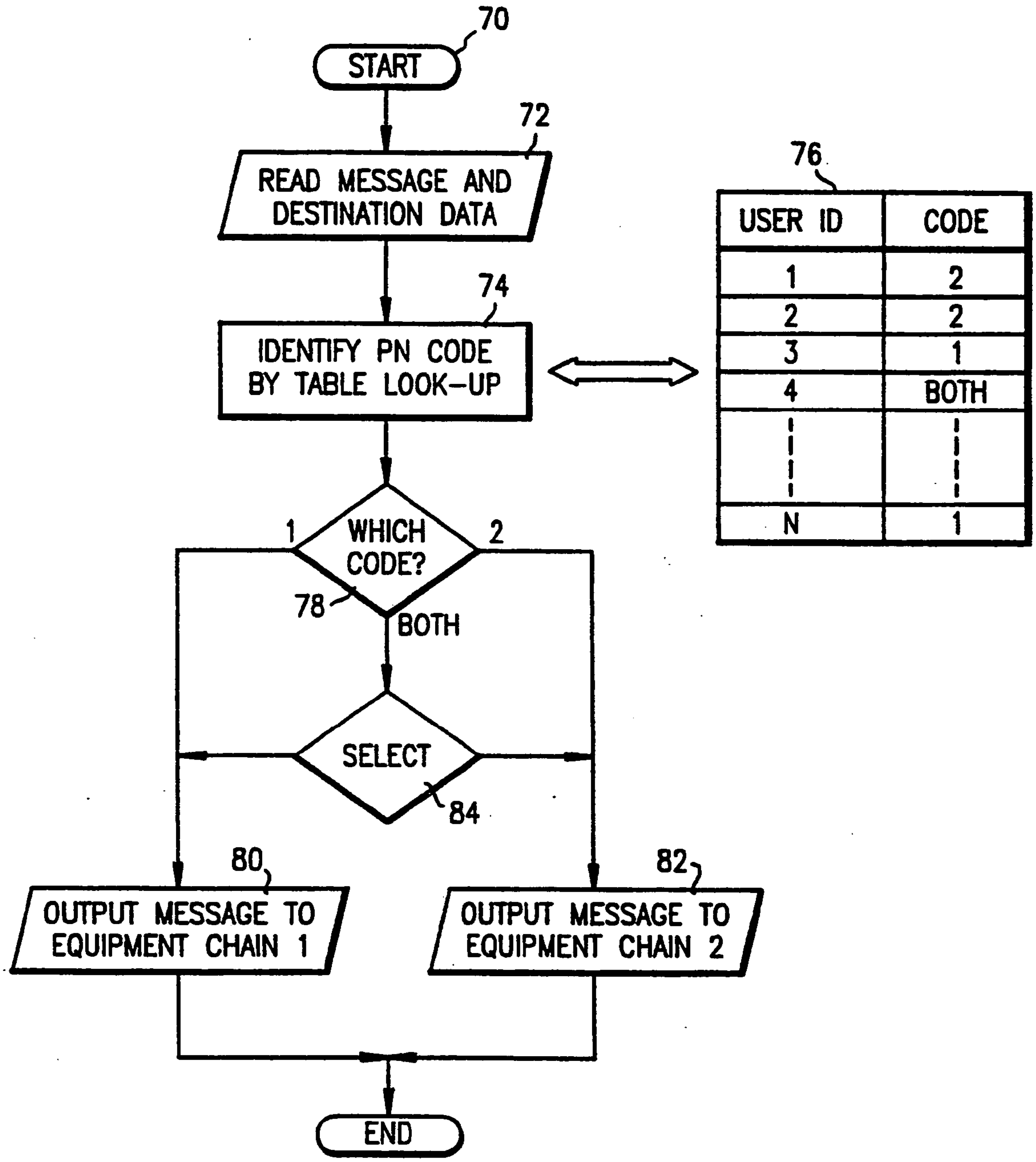
70
START
72
READ MESSAGE AND DESTINATION DATA
74
IDENTIFY PN CODE BY TABLE LOOK-UP
76
USER ID
CODE
1 2
2 2
3 1
4 BOTH
N 1
WHICH CODE?
1
2
78
BOTH
SELECT
84
80
OUTPUT MESSAGE TO EQUIPMENT CHAIN 1
82
OUTPUT MESSAGE TO EQUIPMENT CHAIN 2
END

FIG. 4

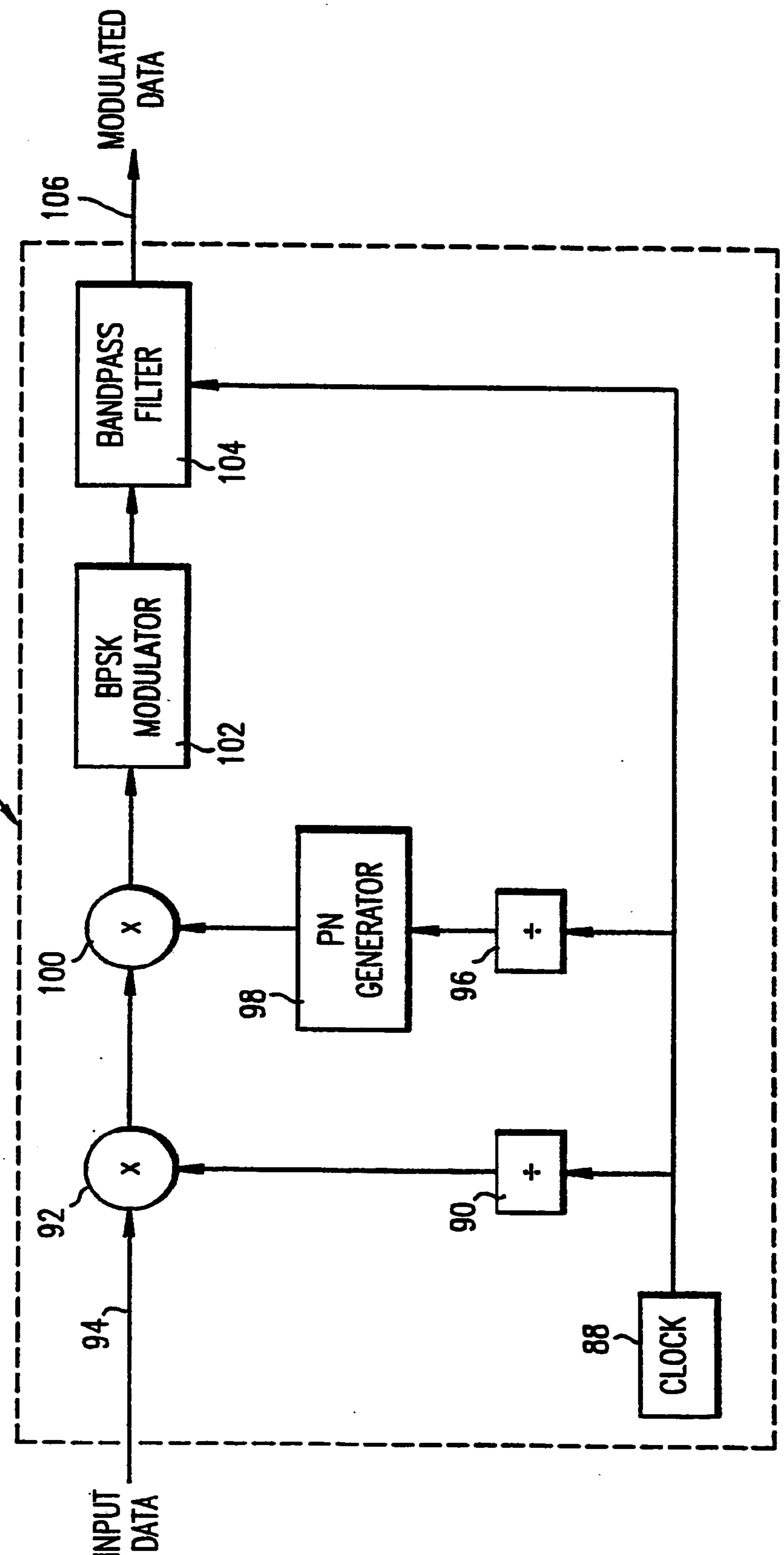
MODULATED DATA
106
BANDPASS FILTER
104
BPSK MODULATOR
102
46
×
100
PN GENERATOR
98
÷
96
×
92
÷
90
94
CLOCK
88
INPUT DATA

FIG. 5

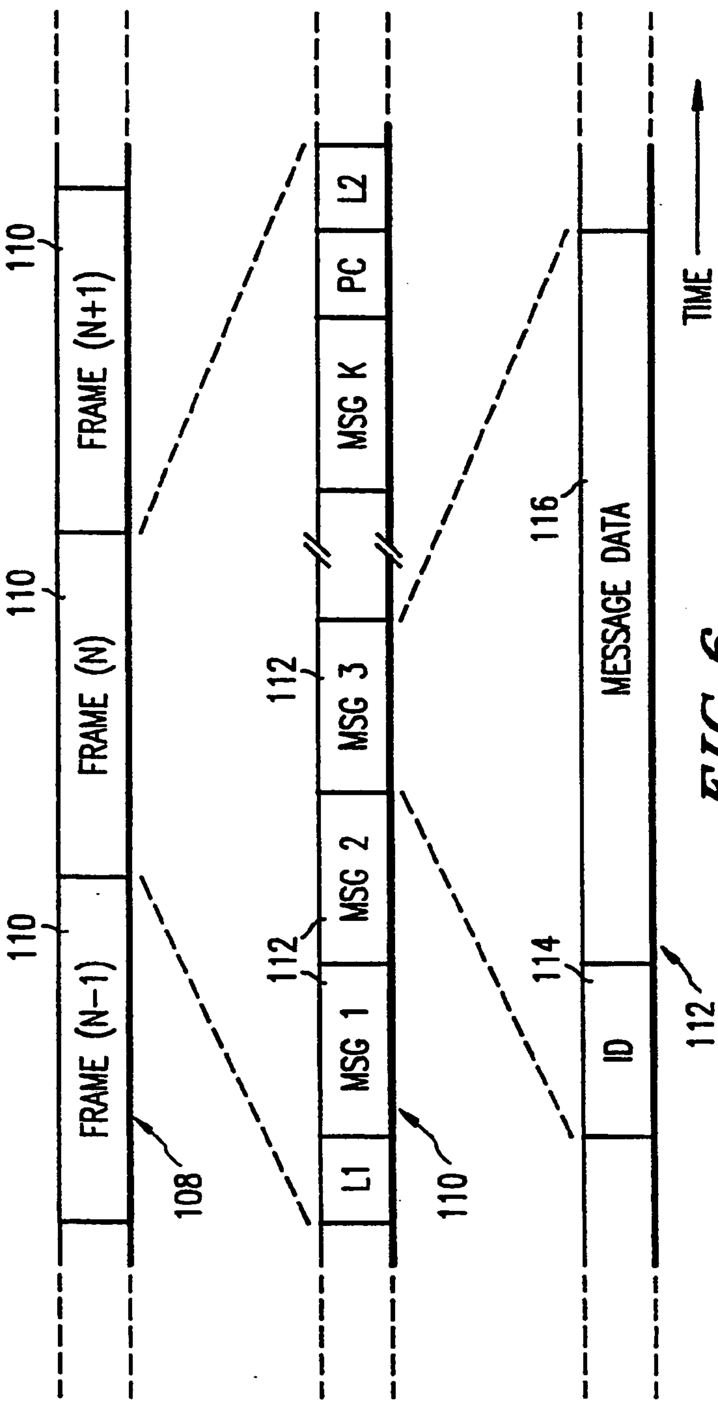
FRAME (N-1)
FRAME (N)
FRAME (N+1)
110
108
L1
MSG 1
MSG 2
MSG 3
MSG K
PC
L2
112
ID
MESSAGE DATA
114
116
TIME

FIG. 6

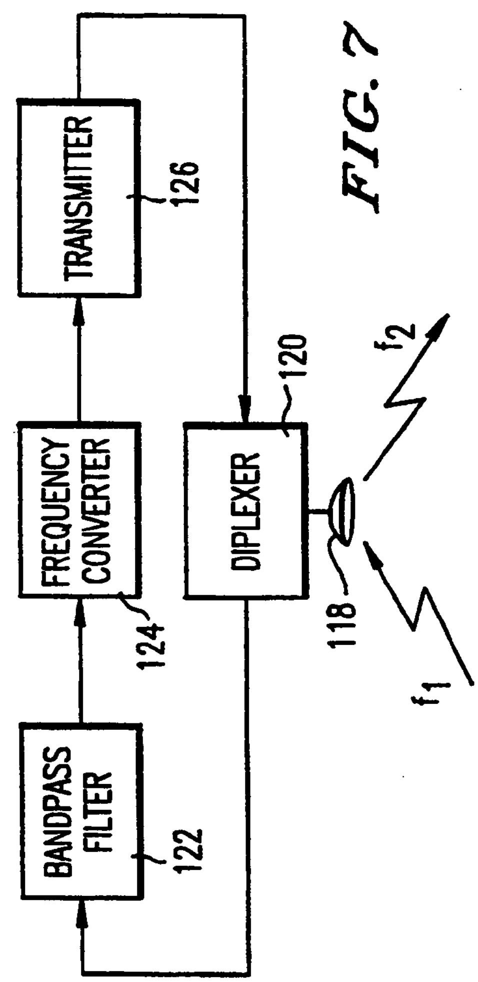
BANDPASS FILTER
122
FREQUENCY CONVERTER
124
TRANSMITTER
126
DIPLEXER
120
118
f_1
f_2

FIG. 7

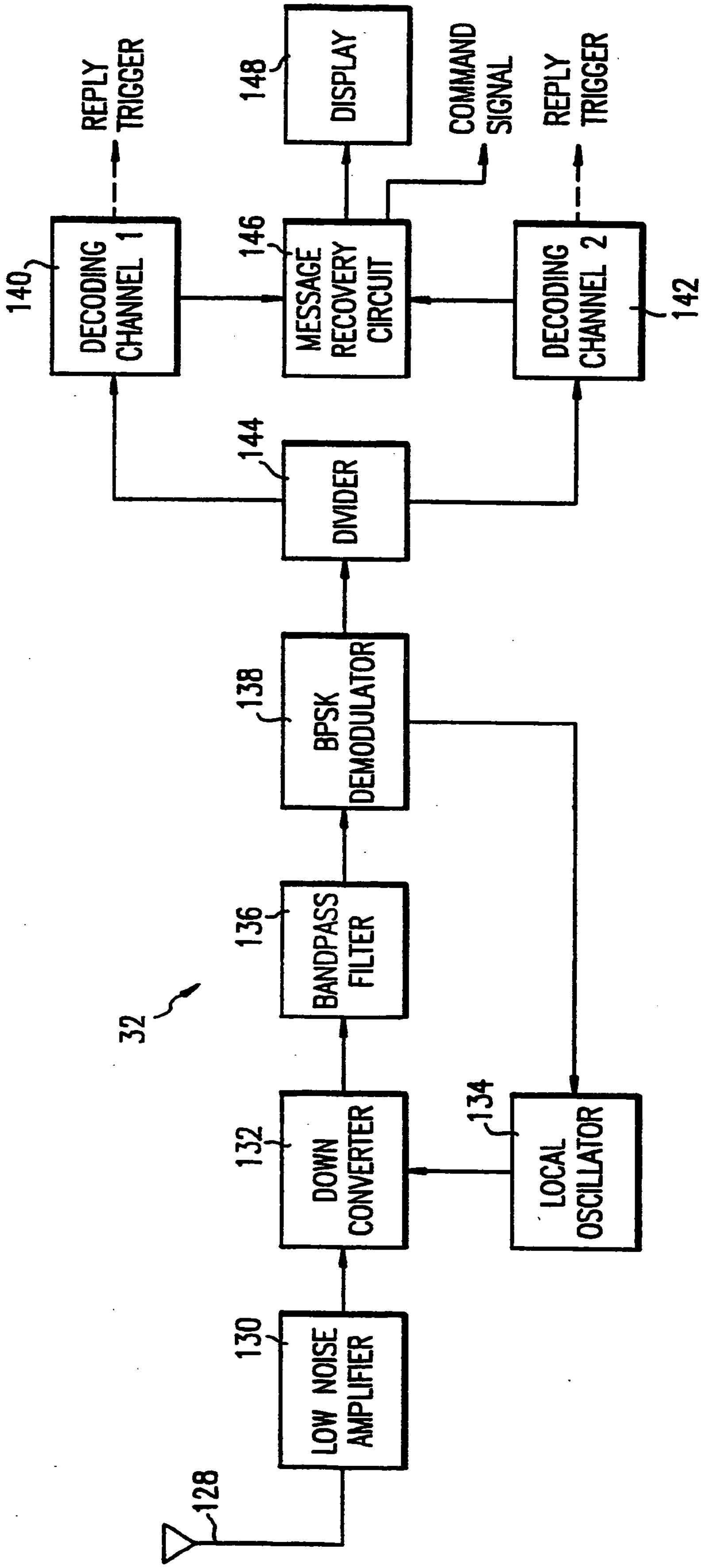
128
LOW NOISE AMPLIFIER
130
DOWN CONVERTER
132
LOCAL OSCILLATOR
134
BANDPASS FILTER
136
32
BPSK DEMODULATOR
138
DIVIDER
144
DECODING CHANNEL 1
140
MESSAGE RECOVERY CIRCUIT
146
DECODING CHANNEL 2
142
REPLY TRIGGER
DISPLAY
148
COMMAND SIGNAL
REPLY TRIGGER

FIG. 8

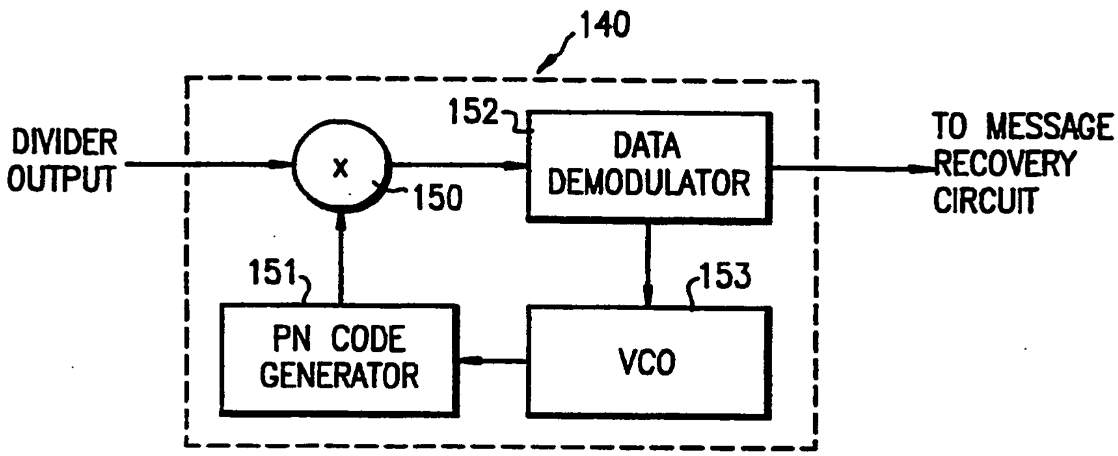
140
DIVIDER OUTPUT
x
150
152
DATA DEMODULATOR
TO MESSAGE RECOVERY CIRCUIT
151
153
PN CODE GENERATOR
VCO

FIG. 9

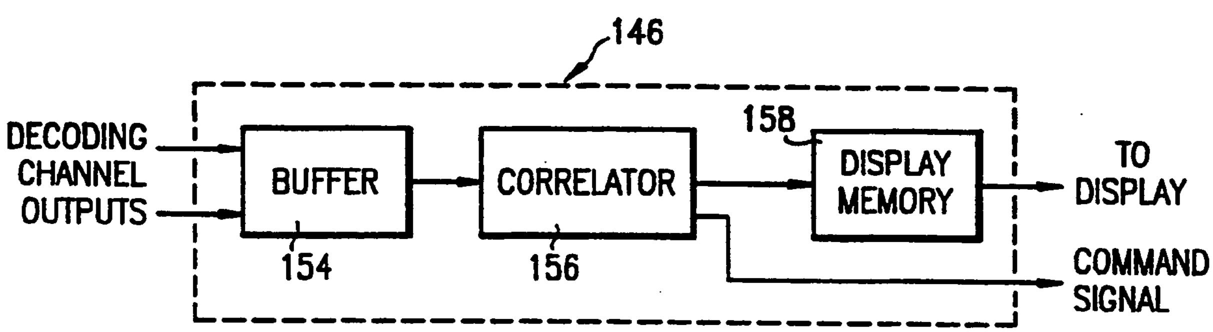
146
DECODING CHANNEL OUTPUTS
BUFFER
154
CORRELATOR
156
158
DISPLAY MEMORY
TO DISPLAY
COMMAND SIGNAL

FIG. 10

INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/02077

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5): H04B 7/00

U.S.Cl.: 455/12, 13, 7; 375/1, 3; 370/104.1; 340/425

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	455/12, 13, 7, 9, 17, 23, 53, 54 375/1, 106, 3; 370/104.1; 340/425

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 4,744,083 (O'Neill et al) 10 May 1988 See entire document	1-3, 7-14, 17, 19, 20
A	US, A, 4,004,098 (Shimasaki) 18 January 1977 See entire document	1-20
A	US, A, 3,879,580 (Schlosser et al) 22 April 1975 See entire document	1-20

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
11 July 1990	16 AUG 1990
International Searching Authority [1]	**Signature of Authorized Officer**
ISA/US	for Donnie L. Crosland NGUYEN NGOC-HO INTERNATIONAL DIVISION Ngoc-Ho Nguyen

Form PCT/ISA/210 (second sheet) (May 1986)